Faculty of Engineering

COMPARISON ON WINDING METHOD FOR ELECTRICAL GENERATOR

Chua Ten Hou

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COMPARISON ON WINDING METHOD FOR ELECTRICAL GENERATOR

CHUA TEN HOU

A dissertation submitted in partial fulfillment
of the requirement for the degree of
Bachelor of Engineering (Hons) in Electronics (Telecommunications)

Faculty of Engineering
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To my beloved family and friends.

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ABSTRACT

Permanent Magnet Synchronous Generator (PMSG) is the most favorable generator in producing the electricity, especially in wind turbine industry. The PMSG has a higher efficiency compared to other generators as its excitation field is provided by the permanent magnet. This is an advantage for the generator as it reduces the maintenance cost of the generator.

A suitable winding method for the PMSG can increase the performance of the generator. There are four types of winding methods that are widely used in the generator which are single layer winding, double layer winding, concentrated winding, and distributed winding. In this thesis, the single layer concentrated winding, double layer concentrated winding, single layer distributed winding, and double layer distributed winding are simulated in Finite Element Method Magnetics (FEMM). The PMSG is simulated and analyzed according to different winding methods. This analysis is aimed to compare different type of winding methods in order to enhance the efficiency of the PMSG.

ABSTRAK

Permanent Magnet Synchronous Generator (PMSG) adalah penjana yang paling baik dalam menghasilkan elektrik, terutamanya dalam industri turbin angin. PMSG mempunyai kecekapan yang lebih tinggi berbanding dengan penjana lain disebabkan medan pengujaannya diperoleh daripada magnet kekal. Hal ini merupakan satu kelebihan untuk generator tersebut kerana ia mengurangkan kos penyelenggaraan penjana.

Kaedah penggulungan yang sesuai untuk *PMSG* boleh meningkatkan prestasi penjana. Terdapat 4 jenis kaedah penggulungan yang digunakan secara meluas dalam penjana iaitu *single layer winding, double layer winding, concentrated winding* dan *distributed winding*. Dalam tesis ini, *single layer concentrated winding, double layer concentrated winding, single layer distributed winding* dan *double layer distributed winding* disimulasikan dengan *Finite Element Method Magnetics (FEMM)*. PMSG disimulasikan dan dianalisiskan mengikut kaedah penggulungan yang berbeza. Analisis ini bertujuan untuk membandingkan kaedah penggulungan yang berbeza bagi meningkatkan kecekapan PMSG.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PM	-	Permanent Magnet
PMSG	-	Permanent Magnet Synchronous Generator
FEMM	-	Finite Element Method Magnetics
PMSM	-	Permanent Magnet Synchronous Machine
MMF	-	Magnetomotive Force
FSCW	-	Fractional-slot Concentrated Winding
IPM	-	Interior Permanent Magnet
RPM	-	Revolutions per Minute
EMF	-	Electromotive Force
SLCW	-	Single Layer Concentrated Winding
DLCW	-	Double Layer Concentrated Winding
SLDW	-	Single Layer Distributed Winding
DLDW	-	Double Layer Distributed Winding

CHAPTER 1

INTRODUCTION

1.1 Overview

Electricity is one of our essential needs especially in our daily life as most of the appliances in the home, office or even factories depend on electricity to function. Almost all the electricity produced in the world is generated by the electric machine. Electricity exists in nature as a form of lightning. It also can be generated from the electrical power generator. Electricity can be produced through various ways such as wind, water, nuclear or even combustion of coal and oil. Figure 1.1 below depicts that the wind energy is the second highest of the renewable energy in the electricity generation which is 3.7% [1].

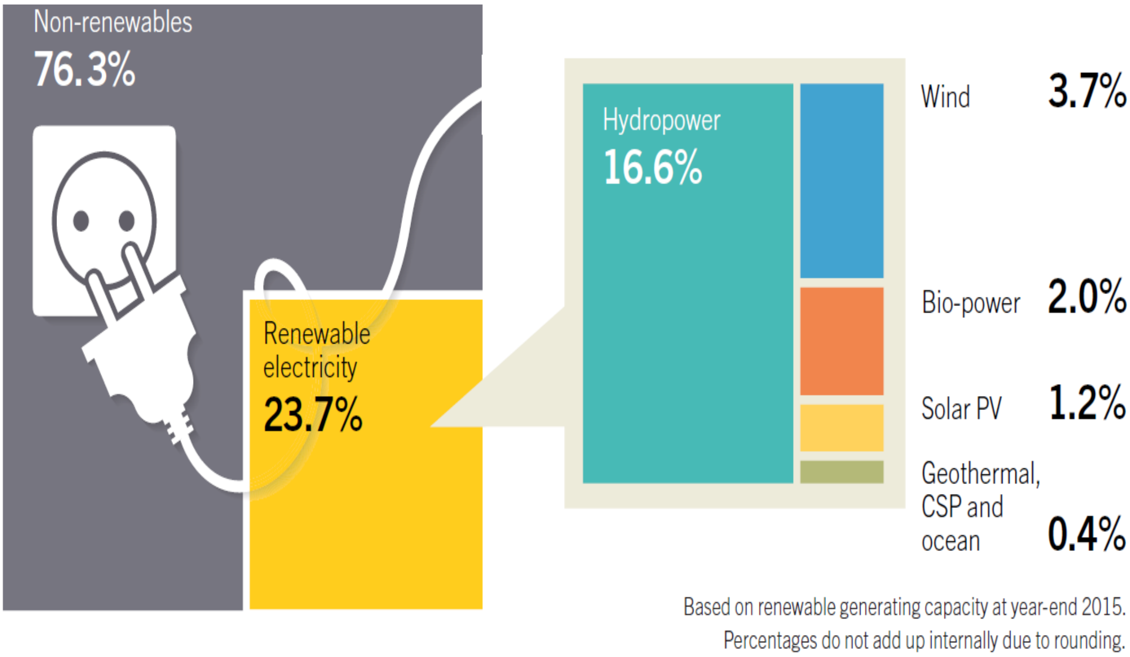

Figure 1.1: Global Electricity Production of Renewable Energy Share 2015 [1]

A synchronous machine is an alternating current rotating machine that its speed is proportional to the frequency of the current in its armature under steady state condition. This means that the magnetic field of the armature currents will rotate at the same synchronous speed as the permanent magnets (PM) or the field current on the rotor. Due to the characteristic of the synchronous speed, the synchronous generator is applied to the constant speed drive.

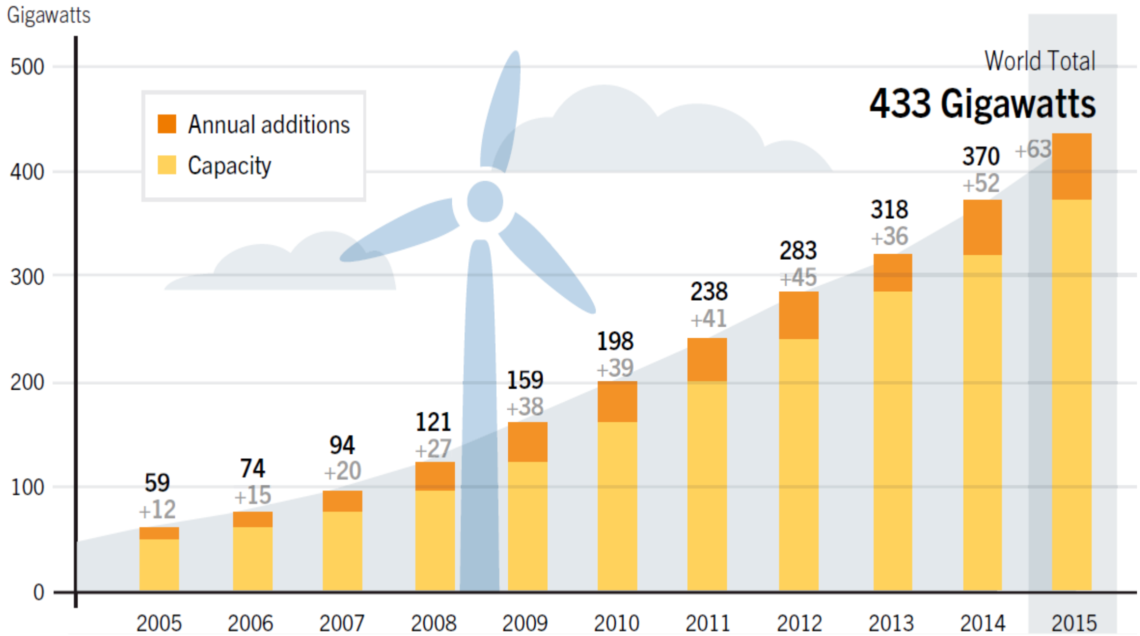

Figure 1.2: Global Capacity of Wind Power in the year 2005-2015 [1]

Figure 1.2 shows that the wind power global capacity had increased continuously for each year from the year 2005 until 2015. In the year 2015, the global capacity for wind power had reached 433 Gigawatts [1]. This concluded that the demand for the electricity from wind energy had risen. In wind turbine industry, permanent magnet synchronous generator (PMSG) is widely used to produce electricity. Permanent magnet is used for the synchronous generator instead of the coil for excitation field. PMSG does not require slip rings to operate. There is no direct current supply that is needed for excitation circuit. Without the need of slip rings, PMSG is easier to be constructed and lower maintenance cost. The permanent magnet minimizes the rotor losses and this indirectly improves the efficiency of the generator.

PMSG offers a great privilege due to its stable operation [2]. However, the construction fee for PMSG is costly due to its rare earth material permanent magnet.

Despite the high cost of the permanent magnet, the PMSG is widely used in the concern of the environmental conservation. The air-gap magnetic flux density also increased with the use of permanent magnet. PMSG has a smaller volume and lower density. The permanent magnet can be positioned inside the rotor or even mounted on the rotor's surface. The maximum efficiency can be achieved by minimizing the air-gap between rotor and stator.

There are various ways for coils to be wound in the stator of the generator. Each of the forms has its own drawbacks and advantages. The main purpose of varying the forms of the coil distribution is to produce three balanced sinusoidal voltages with a little harmonic voltage and current for three phase machine. In other words, the output power is maximized and the losses are minimized with different patterns of coil distribution. The number of slots at the stator can be varied which will affect the manner of the coil connection and hence different winding patterns can be formed.

1.2 Problem Statement

The PMSG is a part of the wind turbine system. Nowadays, as the demand for the electrical energy had increased rapidly around the world, the efficiency for the PMSG is seeking more attention from the researcher. With an attempt to increase the performance of the PMSG, the world non-renewable energy consumption can be reduced and the global warming issue can be minimized or even rectified. Moreover, the global economy will also be improved and this will eventually enhance the quality living of life. Furthermore, a better performance of PMSG can surely aid in the prevention of climate change. All these advantages come with the energy efficiency. Hence, various design on the PMSG had been researched to increase the power output and reduce the losses of the generator.

There is no doubt that the PMSG is well known for its high efficiency and long lasting performance which can be used in wind turbine. However, there are various ways to enhance the performance of the PMSG. One of the factors that determine the efficiency of the PMSG is the winding method. In this thesis, the winding patterns that are compared are single layer concentrated winding (SLCW), double layer concentrated winding (DLCW), single layer distributed winding (SLDW) and double layer distributed winding (DLDW). In order to improve the efficiency of the PMSG, the most suitable winding pattern has to be chosen.

1.3 Objectives

The objectives of this project are:

- To study and investigate the winding methods for PMSG.
- To determine the efficiency of PMSG for each type of the windings.
- To compare the winding methods for the PMSG.
- To perform analytical analysis and simulation by using Finite Element Method Magnetics (FEMM) to maximize the efficiency of the PMSG.

1.4 Expected Outcomes

In this project, the expected outcomes are listed below:

- The winding methods of the stator for the PMSG are studied and compared.
- The simulation of the PMSG is done by using FEMM software.
- The efficiency of each of the winding methods is analyzed and compared.
- The winding method that yields the highest performance of the PMSG is determined.

1.5 Project Outlines

This project contains five chapters. These chapters comprised of Introduction, Literature Review, Methodology, Result and Discussion, and Conclusion and Recommendation. These chapters are arranged from Chapter 1 to Chapter 5 respectively.

Chapter 1 provides a brief introduction to the electricity generation together with a short review on the PMSG, the problem statement, and objectives of this project. The expected outcomes at the end of the project are also included in this chapter.

Chapter 2 reviews and compiles all the studies and research that are related to the project. The topologies for the PMSG, different winding methods of the stator, parameter that determine the efficiency of the PMSG and analysis approach are discussed in this chapter.

Chapter 3 discusses the methodology that is needed to carry out the project. In this chapter, the PMSG model that is used in this project is presented and explained. The terminology and the analytical approach by using the FEMM software are depicted in this section.

Chapter 4 computes the performance of the PMSG either through mathematical calculation or via the 2 dimension simulation of the FEMM. The parameters that affect the efficiency of PMSG is evaluated. All the graphical results and the magnetic field maps are delineated in this chapter.

Chapter 5 concludes all the results of the project and summarize the outcomes. The recommendations after carrying out this project are discussed in this chapter. Any limitation of this project is included too.

CHAPTER 2

LITERATURE REVIEW

2.1 Permanent Magnet Alternating Current Machine

The Permanent Magnet Synchronous Machine (PMSM) can be divided into two categories which are axial field and radial field. For axial field topology, the flux is moving parallel to the rotor shaft whereas the flux is moving along the machine's radius for the radial field topology [3]. The permanent magnet can be placed at a various position on the rotor. The pro and cons of the axial field and radial field topologies are discussed below [4].

Axial field's strengths:

- A balanced rotor-stator attractive forces with two air-gaps.
- The grinding to an arc shape is skipped as the permanent magnets have two planar surfaces.
- There is an adjustable air-gap.
- Magnet retainment is not needed.

Axial field's weakness:

- There is a poor winding utilization.
- Restricted size of the end turns at the internal radius.
- Cogging torque existed.

Radial field's strengths:

- There is no radial force on the rotor.
- Easier removal of heat from the stator winding due to the big surface area of the stator back iron.

- Skewing is not needed.

Radial field’s weakness:

- The magnets surface must be arced.
- Fixed air-gap
- An air-gap is formed between rotor magnets with the rotor back iron.

Figure 2.1 and Figure 2.2 show the axial and radial field structure of PMSM respectively [5].

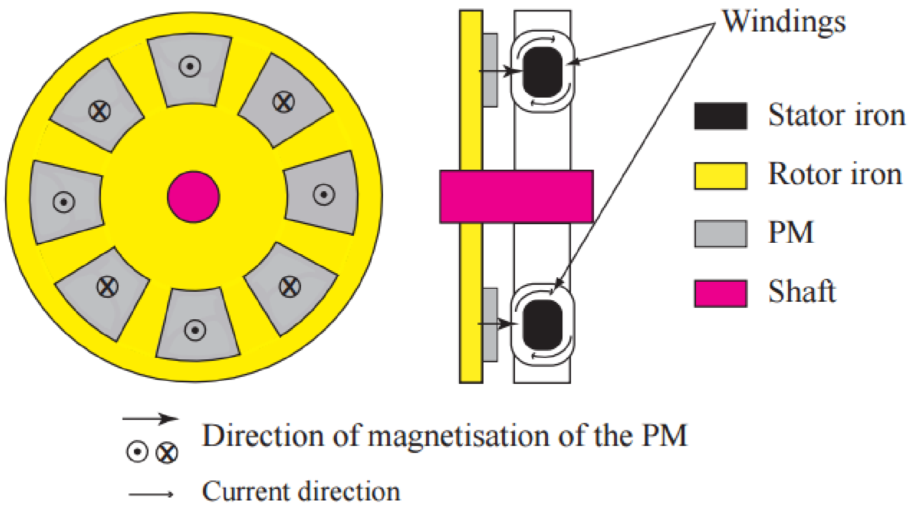

Figure 2.1: Axial Flux PMSM’s Structure [5]

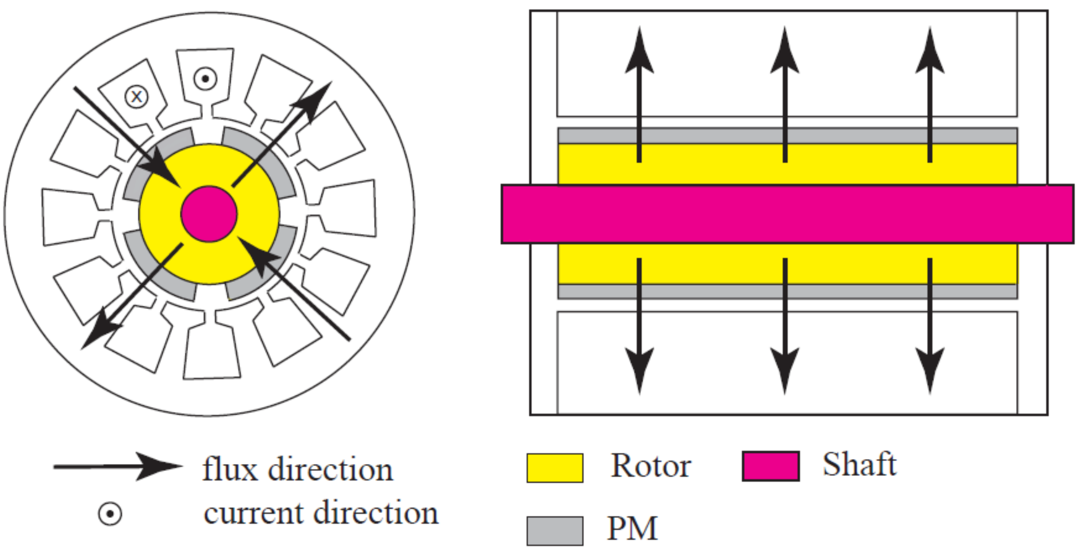

Figure 2.2: Radial Flux PMSM’s Structure [5]

Figure 2.3, 2.4, 2.5 and 2.6 show the radial field of the PMSM with different positions of permanent magnets [3].

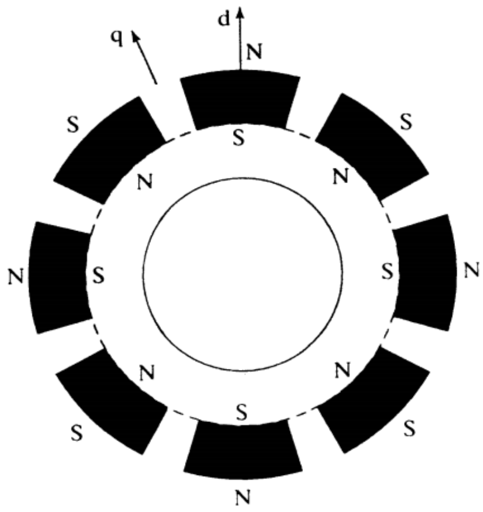

Figure 2.3: Surface PMSM [3]

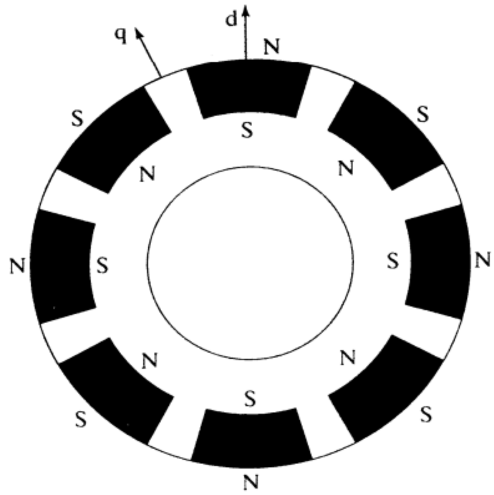

Figure 2.4: Surface Inset PMSM [3]

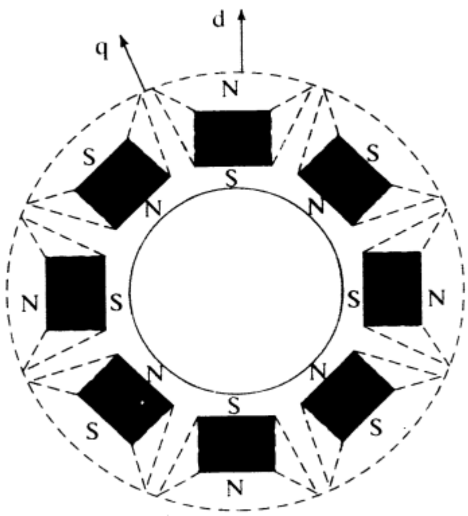

Figure 2.5: Interior PMSM [3]

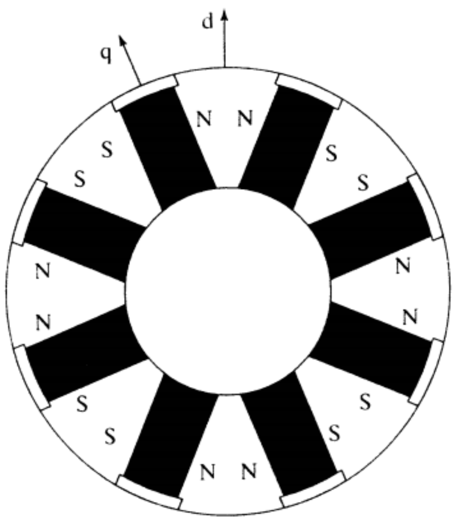

Figure 2.6: Interior PMSM with Circumferential Orientation [3]

The permanent magnets of the surface PMSM are directly mounted on the rotor's surface as shown in Figure 2.3. Figure 2.4 shows that the permanent magnets of the surface inset PMSM are fixed at the rotor inner surface. The Figure 2.5 depicts that the permanent magnets of the PMSM are implanted inside the rotor meanwhile the permanent magnets are aligned in a circular orientation inside the rotor of the PMSM as shown in Figure 2.6.